ESO-2179

Estimation of Dynamic Oligopolistic Interaction: The Case of the Banana Export Market

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October 1994

Paper prepared for presentation at the annual meetings of the Southern Economic Association, Orlando, Florida, 20-22 November, 1994. The authors would like to acknowledge financial support for this research from Regional Research Project NC-194.

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Abstract

In the past two decades, researchers in the field of industrial organization have focused on the use of static, structural econometric models to estimate the degree of market power in domestic industries. However, these studies fail to take into account the multi-period nature of markets. Therefore, it may be more appropriate to use a dynamic approach to estimating the degree of market power. This paper applies a linear-quadratic methodology, developed by Karp and Perloff (1989, 1993a), to the German market for banana imports.

Assuming a quadratic objective function with linear demand and quadratic cost, and a Markov equation that captures the dynamic interaction among firms, a dynamic conjectural variations parameter is derived under open-loop and feedback strategies. Compared to the open-loop conjectural variations parameter, the feedback conjectural variations parameter shows a greater degree of collusiveness. For the purpose of hypothesis testing, standard errors on the conjectural variations parameter are calculated using Taylor expansion and bootstrapping methods. The hypothesis that market structure is perfectly competitive/perfectly collusive is rejected, however, the hypothesis that firms behave in Cournot-Nash fashion could not be rejected.

1. Introduction

In the last decade, there has been renewed interest in conducting empirical analysis in industrial economics, which is now commonly referred to as the "new empirical industrial organization" (NEIO). Compared to the Structure/Conduct/Performance approach of the 1960s and 1970s, which focused on reduced-form, cross-section regression analysis of industries (Schmalensee, 1989), the more recent approach has been characterized by the use of structural econometric models (Bresnahan and Schmalensee, 1987) that estimate the degree of market power in a given market. The key difference between the two methodologies has been that while the former tended to assume the existence of market power across a sample of industries, the latter has been aimed at directly estimating market power in a specific industry.

There have been many applications of the new methodology to a variety of industries (see Bresnahan, 1989; Perloff, 1992), however, most of this empirical work has focused on the estimation of a market power parameter within a static, one-period framework, which may be inappropriate if firms operate in a multi-period environment. Non-cooperative game theory suggests that in a dynamic setting, firms take account of other firms' previous behavior in formulating their strategies. As a consequence, it is possible that collusive equilibria can be obtained in repeated games (Fudenberg and Tirole, 1989). In addition, it may be more appropriate to use a dynamic framework when there are substantial adjustment costs in changing production from one period to another (Karp and Perloff, 1993a), a characteristic that is particularly relevant to agricultural commodity markets.

As well as being static in nature, virtually all of the empirical studies of market power in the NEIO have focused on domestic markets as opposed to export markets, the most notable exceptions being Buschena and Perloff (1991), coconut oil export market; Karp and Perloff (1989, 1993b), rice and coffee export markets; and Lopez and You (1993), Haitian coffee exporting. Estimating the degree of imperfect competition in international markets is important in the context of developments over the past fifteen years in international trade theory (Helpman and Krugman, 1985, 1989). The key characteristic of the so-called "new trade theories" (NTTs) is the explicit assumption of imperfectly competitive markets. In models explaining the structure of trade, it is commonly assumed that scale economies can lead to specialization and export in monopolistically competitive markets, e.g. Krugman (1979). The NTTs have also made a significant contribution to understanding how imperfect competition can affect the gains from trade liberalization, e.g. Smith and Venables (1988), and, also, how different trade instruments can have differential welfare effects when markets are oligopolistic, e.g. Krishna (1989). These developments suggest there is a premium on verifying empirically whether an international market(s) is(are) imperfectly competitive.

The objective of this paper is to estimate the degree of non-competitiveness in the German market for banana imports using a linear-quadratic dynamic game model, originally developed by Karp and Perloff (1989, 1993a, 1993b). Using both open-loop and feedback strategies, a dynamic conjectural variations parameter is estimated, where the conjectural variations parameter nests the well-known market structures of perfect competition, Cournot-Nash and collusion. The procedure involves the estimation of a demand function and a Markov equation, the parameters of which are then used in the solution to a dynamic programming problem from which the conjectural variations parameters are then derived.

The German banana market was chosen as a good candidate for application of this particular technique for three inter-related reasons:

- first, there is circumstantial evidence that the banana export industry is imperfectly competitive. World trade in bananas, valued at $5.1 billion in 1991 (FAO, 1993), is dominated by three multinational firms[1], United Brands (Chiquita), Standard Fruit (Dole), and Del Monte (Read, 1983). Between them, these three firms account for 70 percent of the world market and 66 percent of the European market, United Brands alone accounting for 43 percent (McCorriston and Sheldon, 1994). With respect to Germany, three firms (United Brands, Standard Fruit and Noboa) account for about 72 percent of the market. This apparently oligopolistic market

1. In contrast to the present study, Karp and Perloff (1989, 1993b) in their analysis of the rice and coffee markets assume that the relevant decision-making agents are countries through their export marketing boards.

structure derives largely from the existence of economies of scale in refrigerated shipping and distribution (Read, 1994).

- second, in terms of a dynamic model structure, there are substantial adjustment costs in the production and export of bananas: there is a gestation period of about a year and a quarter between the previous and current harvest; plantation production is highly capital-intensive; transportation requires refrigeration and careful shipping.

- third, the German banana import market has recently been subjected to the implementation of import quotas as a part of changes to the European Community's (EC) banana import regime (Read, 1994). As has been shown in several papers (Hwang and Mai, 1988; Krishna, 1989) import quotas can have the effect of "facilitating" collusion in oligopolistic markets, the extent depending on the nature of competition prior to implementation of the quota.

The paper is organized as follows: Section 2 describes the linear-quadratic dynamic model used in this paper. Essentially, this involves the estimation of a demand function for banana imports in Germany, and a Markov equation that captures the strategic interaction among firms, based either on open-loop or feedback strategies. The parameters of these equations are then used in the solution to a dynamic programming problem in order to derive a dynamic conjectural variations parameter. Section 3 describes the data used to estimate the above parameters and reports the results of the econometric analysis, and Section 4 summarizes.

3. A Linear-Quadratic Dynamic Game

In the present paper, the degree of market power enjoyed by the top three firms in the German market for banana imports, is evaluated by estimating a dynamic conjectural variations parameter[2] in the context of a linear-quadratic dynamic model[3]. When modeling oligopolistic markets as dynamic games, two important equilibrium concepts are commonly used: *open-loop* and *feedback* Nash equilibrium. These concepts are borrowed from optimal control theory which often distinguishes between open-loop and feedback solutions to optimal control problems. In an open-loop equilibrium, controls (i.e. moves made by a firm that constitute its strategy), are a function of time and the initial state. The open-loop strategy space S_i^O is defined as:

$$S_i^O = [x_i(y(0),t) \mid x_i(y(0),t) \text{ is a continuous function of time } t, \ \forall \ t \geq 0],$$

where $x_i(.)$ is the control variable (e.g. rate of change of output) of the i^{th} firm, $y(0)$ is the initial state (e.g., initial output). Since moves are independent of the current state of the system, and a firm is committed to a preannounced plan not anticipating any response, this equilibrium is not subgame perfect. This strategy is naive as firms take no account of the reactions of the other firms. In this sense, the open-loop equilibrium is the dynamic analog of the static Nash equilibrium where firms assume the output choices of opponents as given.

In contrast, in a feedback equilibrium, players design their optimal policies as decision rules dependent on the current state of the game. The feedback strategy space is defined as:

$$S_i^F = [x_i(y(t),t) \mid x_i(y(t),t) \text{ is a piecewise continuous function of time } t \geq 0, \text{ and Lipschitz}^4\text{-continuous w.r.t. } y(t) = (y_1(t),\ldots,y_n(t))].$$

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2. The term dynamic conjectural variations was first used by Riordan (1985).

3. The term linear-quadratic comes from optimal control theory, and refers to a problem where the objective function is quadratic and the constraints are linear. The advantage of using a linear-quadratic approach is that open-loop and feedback strategies can be easily compared. It is also possible to solve analytically for the conjectural variations parameter in the linear-quadratic case.

4. With respect to the state variable, the Lipschitz condition states that, there exists a non-negative constant K; such that: $\|f(t,y) - f(t,\bar{y})\| \leq K \|y-\bar{y}\|, \ \forall \ t \in [t_0,T]; \ y,\bar{y} \in R^n$.

Since state variables at time t summarize the latest available information about the system at time t, and since firms take the mechanism for determining future behavior as given, feedback strategies can be referred to as Markov strategies and a feedback equilibrium can be considered a subgame perfect equilibrium, and firms' period of commitment is zero. The Markov equation is given as $q_t = Gq_{t-1}$, which depicts the linear decision rules for the firms, where q_t is the output vector of firms at time t. It should be noted at this point that the adjustment paths for the open-loop and feedback equilibria are the same for the limiting cases of perfect competition and collusion with symmetric firms (see Karp and Perloff, 1993a).

Given the open-loop strategy, and three symmetric firms in the German banana market, the objective (profit) function of an individual firm over an infinite time-horizon is assumed to take the following form:

(1) $$\sum_{t=1}^{\infty} \beta^{t-1}\left[(P_t - \theta_i - 0.5\phi_i q_{it})q_{it} - (\omega_i + 0.5\delta_i u_{it})u_{it}\right]$$

where P_t is the German retail price of bananas in period t, q_{it} is the quantity of bananas exported to Germany by the i^{th} firm in period t, u_{it} is the change in exports of firm i from period $t\text{-}1$ to period t, and β is the discount factor. The term $(\theta_i + 0.5\phi_i q_{it})q_{it}$ represents the quadratic production cost, and $(\omega_i + 0.5\delta_i u_{it})u_{it}$ represents quadratic production adjustment cost. The inverse demand function P_t is assumed to take a linear form:

(2) $$P_t = a - b\sum_{i=1}^{n} q_{it} = a - bQ_t$$

Converting the objective function (1) into matrix form, and deriving the first-order-condition restrictions, gives the following matrix equation (see appendix A):

(3) $$K_i V_i = [G^{-1}(I - G)(I - \beta G)]' e_i \delta_i$$

V_i is a three into one column vector with one in the i^{th} row and V_{ij} and V_{ik} in the remaining rows, where V_{ij} is defined as du_{it}/du_{jt}, and similarly V_{ik}. In deriving equation (3), no symmetry assumptions are made, however, for analytical tractability, symmetry is introduced at this stage. Specifically, it is assumed that $V_{ij} = V \; \forall \; i,j$; $\delta_i = \delta \; \forall \; i$; and G is symmetric such that elements $G_{ij} = g_1 \; \forall \; i=j$; $G_{ij} = g_2 \; \forall \; i \neq j$. It should be noted that the dynamic conjectural variations parameter V ranges from -1/(n-1) for the case of perfect competition, where n is the number of firms, through 0 for Cournot-Nash, to 1 for perfect collusion, the same range as in a static framework.

Under the open-loop strategy concept, firms decide the optimal export path at the start of the game and do not revise their moves contingent on what the other firms might do in subsequent periods. However, this assumption is too naive, and it is necessary to consider a subgame perfect feedback strategy, where optimal export choices depend not only on time but on the current state of the system. The value function method of dynamic programming is used to set up the dynamic objective function for this kind of firm behavior. If the value of the present and discounted future profits of firm i can be expressed as $J_i(q_{t-1}, V_i)$, where V_i is defined as above, then firm i's dynamic programming profit maximization problem can be written as:

(4) $$J_i(q_{t-1},V_i) = max\left[(P_t-\theta_i-0.5\phi_i q_{it})q_{it}-(\omega_i+0.5\delta_i u_{it})u_{it}+\beta J_i(q_t,V_i)\right].$$

Converting this objective function into matrix form, and deriving the first-order-condition restrictions gives the following matrix equation (see Appendix B):

(5) $$[K_i + \beta W_i + (e_i e'_i + \beta X_i)\delta_i]' V_i = [G']^{-1} e_i \delta_i \equiv y_i \delta_i \; .$$

Again, no symmetry assumptions are required for deriving this condition, however, the symmetry requirements used in the open-loop case are introduced here too.

As is shown in detail in Appendices A and B, matrix equations (3) and (5) have two unknowns, the conjectural variations parameter V and the cost of adjustment parameter δ. The rest of the matrices in these equations are expressed in terms of the slope parameter of the inverse demand function, b, and a lagged coefficient matrix G from the Markov equation. Specifically, matrix K_i is expressed in terms of b, matrix X_i is expressed in terms of G, and matrix W_i is expressed in terms of both b and G. Therefore, it is necessary to estimate the matrix G, and recover the parameter b in order to solve matrix equations (3) and (5) for V and δ. The estimation procedure followed is outlined in the next section of the paper.

3. Empirical Analysis

(i) Estimation of Demand and Markov Equations

In order to estimate the parameter b, a linear demand function was specified for the German banana market as follows:

(6) $$Q_t = \alpha_0 + \alpha_1 P_t + \alpha_2 Z_t + \alpha_3 T + \alpha_4 TT + \varepsilon_1$$

Q_t represents the total quantity of bananas imported annually into Germany over the period 1970-1992. P_t represents the real retail price of bananas; Z_t is the German population aged 65-and-above, and T and TT are the trend variables. The demand parameter $b=1/\alpha_1$. Conspicuously absent explanatory variables in (6) are the prices of substitute fruits, income and the total population of Germany. As reported by the World Bank (1985), the cross-price elasticity of bananas with other fruits is very low. It is reported as 0 in Germany, which is similar to estimates for other developed countries, e.g. Huang (1993) reports a value of -0.08 for the cross price elasticity between bananas and oranges in the US. Thus, the choice of bananas in consumption is a matter of customer preference, and other fruits are not accepted as ready substitutes.

The World Bank (1985) also reports that banana consumption is only responsive to income in countries where per capita GNP is less than \$1500. In countries like Germany, with a very high per capita income, banana consumption has reached saturation level with respect to income variations. In addition, the population of Germany has been constant over the time period under consideration. However, the German population is ageing over time, and, therefore, population in the age cohort 65-and-above is growing. Interestingly, a report by the European Commission (1976) states that bananas are regarded as a health food, and they are an important part of the diet of the sick and very old. This justifies the inclusion of the variable Z_t in the demand equation.

In addition to estimating *b*, the dynamic model requires estimation of a system of Markov equations, one for each firm, where the banana exports of the three multinational firms q_{it}, $i=1,..,3$, are regressed on the lagged values of their own exports q_{it-1} to Germany and the lagged values of exports of the other multinational firms q_{jt-1}, $i \neq j$.

Table 1 summarizes and describes the variables used in the estimation procedure. Annual data on aggregate quantities of bananas imported into Germany (Q_t), retail prices (P_t), and import prices (W_t)[5] were collected for the period 1970-1992 from the Food and Agriculture Organization (FAO) publications: *World Banana Economy* (1983) and *Banana Statistics* (1992). Exogenous demographic variables (Z_t) were collected from Warnes (1993), and the International Labour Office (ILO) publication: *From Pyramid to Pillar* (1989)[6]. Other exogenous variables used are a time trend (*T*) and a squared time trend (*TT*). A consumer price index, used for deflating the nominal variables was collected from the International Monetary Fund (IMF) publication: *International Financial Statistics* (1992, 1994). Quantities of bananas exported to Germany by

5. Import price refers to the f.o.r. price charged by importers to wholesalers at the port of Hamburg.

6. Total population figures were available for every year; however, population for age 65-and-above, was reported as a percentage of total population every five years. Other values were interpolated.

the individual multinational firms were not available directly; however, market shares of multinational firms in the German banana market were available for a certain number of years. These market shares were collected from the magazine, *International Fruit World* (1988), and the FAO publications, *World Banana Economy* (1983, 1986).

Table 1: Description of Variables

Variable	Description
P_t	Real retail price of bananas in German market: DM/tonne
Q_t	Total quantity of bananas imported into Germany: thousand tonne/year
q_{1t}	Quantity imported into Germany by Bonita: thousand tonne/year
q_{2t}	Quantity imported into Germany by Chiquita: thousand tonne/year
q_{3t}	Quantity imported into Germany by Dole: thousand tonne/year
q_t	Column vector of q_{1t}, q_{2t} and q_{3t}
q_{1t-1}	One year lagged quantity imported into Germany by Bonita
q_{2t-1}	One year lagged quantity imported into Germany by Chiquita
q_{3t-1}	One year lagged quantity imported into Germany by Dole
q_{t-1}	Column vector of q_{1t-1}, q_{2t-1} and q_{3t-1}
T	Time trend = 1, 2, ...
TT	Squared time trend = 1, 4, ...
W_t	Real import price of bananas in German market: DM/tonne
Z_t	German population: Age 65-and-above

Instrumental Variables was used to estimate the demand function (6), where the instruments used were import price, population aged 65-and-above, time and time-squared. The results of the estimation are presented in Table 2, indicating that the R-square between observed and predicted is 0.95. Although the Durbin-Watson ratio lies in the inconclusive range for rejecting the hypothesis of the existence of autocorrelation, it is also clear that it is very close to the upper bound where the hypothesis of the existence of autocorrelation can be rejected. In the above regression, the relevant parameter α_1= -0.32 is statistically significant at the 1 percent level.

Table 2: Estimation of the Demand Function

$$Q_t = \underset{(1.11)^*}{684} - \underset{(-3.6)}{0.32P_t} + \underset{(1.80)}{106Z_t} - \underset{(-11.4)}{80T} + \underset{(13.0)}{4.2TT}$$

R-square between observed and predicted = 0.95
D_L=0.77 < $DW_{(23,4)}$=1.48 < D_U=1.53 at 1% significance.

*Figures in parenthesis refer to t ratios.

Appendix A and Appendix B show that matrix G establishes a relationship between q_t and q_{t-1} given by: $q_t = Gq_{t-1}$. To recover matrix G, this relationship is estimated using Zellner's (1962) seemingly unrelated equations (SURE) method. The model requires restricting the elements of the G matrix such that the own lagged coefficients (g_1) are the same for the three firms, and lagged coefficients for the other firms (g_2) are the same for the three firms. The F statistic for imposing these restrictions is 1.6, and the critical value for testing the restrictions, F(7,36) is 2.3 at the 5 percent significance level. Therefore, the restrictions cannot be rejected. Since the restrictions could not be rejected, they were imposed, and then the regression equations were estimated, the results being presented in Table 3.

It should be noted that the equations were estimated for 16 observations. While market share data were simply not available for some of the earlier years in the 1970s, the most recent three years were excluded because of an unusual export trend generated by expectations about the EC's common import policy for bananas. By the end of 1992, the EC was deliberating on setting common quotas and tariffs on banana imports. In light of this, the banana multinationals started exporting large amounts of bananas to the EC, expecting that the level of quotas would be influenced by the amounts imported in recent years. Therefore, recent exports of bananas do not reflect strategic interaction of firms, but were instead the result of an anticipated exogenous policy change.

Table 3: Banana Export Adjustment (Markov) Equation.

	Bonita: q_{1t}	Chiquita: q_{2t}	Dole: q_{3t}
Time trend	2.43	3.85	2.36
	(6.10)*	(5.20)	(4.95)
Own lagged exports (g_1)	0.85376	0.85376	0.85376
	(22.97)	(22.97)	(22.97)
Lagged exports of	-0.03485	-0.03485	-0.03485
other firms (g_2)	(-3.22)	(-3.22)	(-3.22)
R-square	0.97	0.83	0.51
Durbin-Watson	2.6	1.4	1.3
Durbin's h	-1.53	1.15	1.47

*Figures in parenthesis refer to t ratios.

The Durbin-Watson test is not valid for the estimated equations since they have a lagged dependent variable as one of the explanatory variables. For this reason, Durbin's h test was performed. For all three equations, the test statistic is less than the critical value of ±1.645 at the 5 percent significance level. Therefore, the hypothesis that there is no first-order autocorrelation cannot be rejected. Further, the coefficients g_1 and g_2 do satisfy the required stability conditions, i.e., $(-1 < g_1 + (n-1)g_2 < 1)$ and $(-1 < g_1 - g_2 < 1)$.

(ii) Estimation of V and δ

Having estimated the G matrix, and the slope of the inverse demand function b, and having assumed $V_{ij} = V$, $\delta_i = \delta$, matrix equations (3) and (5) can now be solved for V and δ. Both of the matrix equations now represent a system of three equations with two unknowns. It can also be noted that the rank of the matrices in (3) and (5) is two, therefore, only the first two equations need to be solved simultaneously to recover the values of V and δ. It turns out that, in both cases, V is a function of G alone, and δ is a function of both b and G. For the open-loop case, a unique solution exists for V; however, for the feedback case, there are two solutions that emerge from solving a quadratic equation in V. One solution is close to the open-loop value, and the other is infeasible ($V < -0.5$ or $V > 1$). Therefore, only the feasible root is chosen as the solution. The relevant algebra is described in Appendix C.

The solutions to both the open-loop and feedback strategies satisfy the restrictions required by theory, i.e.: $-0.5 \leq V \leq 1$ and $\delta > 0$. No ready standard errors are available for V, because V is not retrieved directly from a regression equation. However, standard errors can be calculated for V using the Taylor expansion method[7]. The results of this procedure are summarized in Table 4. The subscripts of V, o and f, refer to the open-loop and feedback strategies respectively, and the superscript c refers to classical estimates, named as such to distinguish them from the bootstrap estimates that are discussed subsequently.

The results show that both values of V are positive, however, the hypothesis of Cournot-Nash behavior cannot be rejected. The hypothesis of collusive behavior is also rejected for both

7. We benefitted from an e-mail discussion with Professor Perloff on how to employ the Taylor expansion method to calculate the standard error of V, and he kindly made available a copy of the original program for doing this.

types of firm behavior. Under the open-loop strategy assumption, the hypothesis of perfect competition cannot be rejected. Only in the case of feedback strategies, can the hypothesis of perfect competition be rejected.

Table 4: Classical Estimates of Dynamic Model.

V_o^c	δ_o^c	V_f^c	δ_f^c
0.08 (0.36)*	0.187 -	0.20 (0.33)	0.191 -

Hypothesis	Test Statistic	Remark
$H_0{:}V_o^c$=-0.5, $H_1{:}V_o^c$>-0.5	1.60	Cannot reject H_0 at 5% or 1%.
$H_0{:}V_o^c$=0, $H_1{:}V_o^c \neq 0$	0.22	Cannot reject H_0 at any level.
$H_0{:}V_o^c$=1, $H_1{:}V_o^c$<1	2.50	Reject H_0 at any level.
$H_0{:}V_f^c$=-0.5, $H_1{:}V_f^c$>-0.5	2.13	Reject H_0 at 5% & 2.5%.
$H_0{:}V_f^c$=0, $H_1{:}V_f^c \neq 0$	0.60	Cannot reject H_0 at any level.
$H_0{:}V_f^c$=1, $H_1{:}V_f^c$<1	2.42	Reject H_0 at 5% and 1%.

*Figures in parenthesis are standard errors.

As an alternative to the classical estimates derived from the Taylor expansion, a bootstrap procedure can also be utilized. The bootstrapping method (Efron, 1979) is a computer-intensive, nonparametric approach to statistical inference based on data resampling. Freedman and Peters (1984) have shown that when lagged endogenous variables are used as explanatory variables, and there is no autocorrelation, a model can be bootstrapped by resampling the rows of the original data. The Markov equation has lagged endogenous variables as explanatory variables, and Durbin's h test shows that there is no first-order autocorrelation, therefore, bootstrapping was performed by resampling the original data with replacement. In the present context, this involves bootstrapping the Markov equation, and generating numerous values of g_1 and g_2. These values, in turn, are used to calculate V and δ, along with their mean values and standard errors.

The results of this procedure are given in Table 5, where superscript B refers to the bootstrap estimate. Resampling and regressing the data 1000 times with replacement, the inequality restrictions on g_1 and g_2, and V and δ are imposed, and constrained estimates of V and δ are derived. While the estimates of V are a little lower than in the classical case, their relative position is maintained. The standard errors of V show a similar pattern. Also, the values of δ are higher than in the classical case, but their relative position is maintained. The standard errors of δ are also calculated based on bootstrapping the Markov equations that generate multiple values of g_1 and g_2. However, δ is a function not only of g_1 and g_2, but also of b, the inverse demand slope, thus, simultaneous bootstrapping of b is also necessary. However, for the present analysis b is assumed to be given, and bootstrapping is performed only on the Markov equation. Therefore, it would be correct to describe the standard errors of δ as pseudo-standard errors.

Table 5: Bootstrapping* of Dynamic Model.

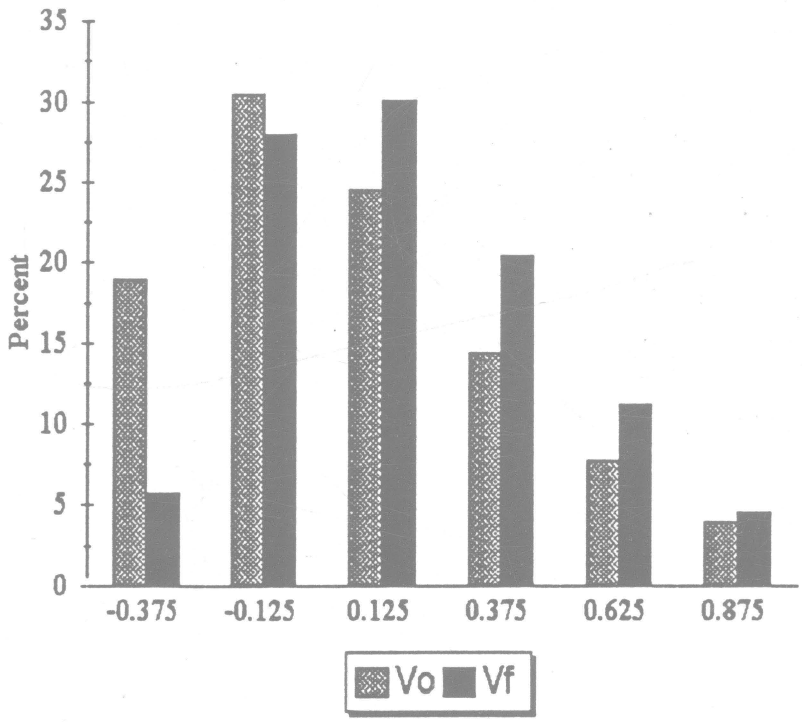
		Open-loop	Feedback
Mean values of V and δ		V^B_o=0.06, δ^B_o=0.22	V^B_f=0.17, δ^B_f=0.23
Standard error		0.33, 0.13	0.30, 0.13
Values rejected because	Unstable	0.2%	0.2%
	$\delta < 0$	2.8%	0.0%
	$V < -0.5$	2.8%	2.8%
	$V > 1$	8.7%	8.7%

*1000 iterations performed.

Having bootstrapped the values of V, it is an interesting exercise to look at how the Vs are distributed over the feasible range. Figure 1 indicates that the distribution of the open-loop

Vs has a thicker left tail while the distribution of the feedback *Vs* has almost symmetric small tails. The concentration of values is in the interval ($-0.25 < V < 0.5$). The percentage of *Vs* lying in this range is nearly 70 percent for the open-loop *Vs*, and nearly 79 percent for the feedback *V*.s Similarly, Figure 2 shows that the value of δ is concentrated in the interval 0.1 to 0.3. The highest frequency being in the range 0.1 to 0.2.

Figure 1: Distribution of *Vs*.



Game theory suggests that the values of V must converge when markets are perfectly competitive or (perfectly) collusive. i.e. the values of V_o and V_f must be the same at $V = -0.5$ and $V = 1$. In a perfectly competitive market (where $n \rightarrow \infty$) firms are mere price takers, and, thus, have no effect on the behavior of other firms or the market price. Therefore, open-loop and feedback behavior should converge. Similarly, in the case of either a perfectly collusive or monopoly market, there is no strategic interaction among firms since firms either form a cartel or there is only one firm in the market. Therefore, once again, open-loop and feedback behavior should converge. In short, in a perfectly competitive or monopolistic market, firm(s) is/are playing a game against nature and not against each other. This intuition then, can be verified by looking at the bootstrapped values of *V*. In Figure 3, selected values of V_o are plotted on the x-axis, and corresponding values of V_f (and V_o too) are plotted on the on y-axis.

The figure shows that V_o and V_f do converge to each other at the values -0.5 and 1, and for other values, V_f is higher than V_o.

Figure 2: Distribution of δs.

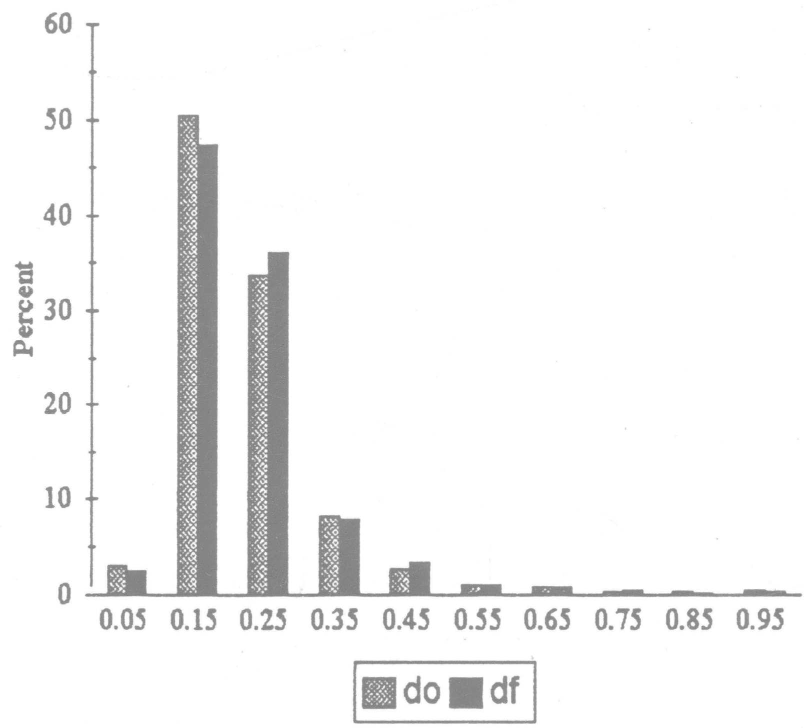
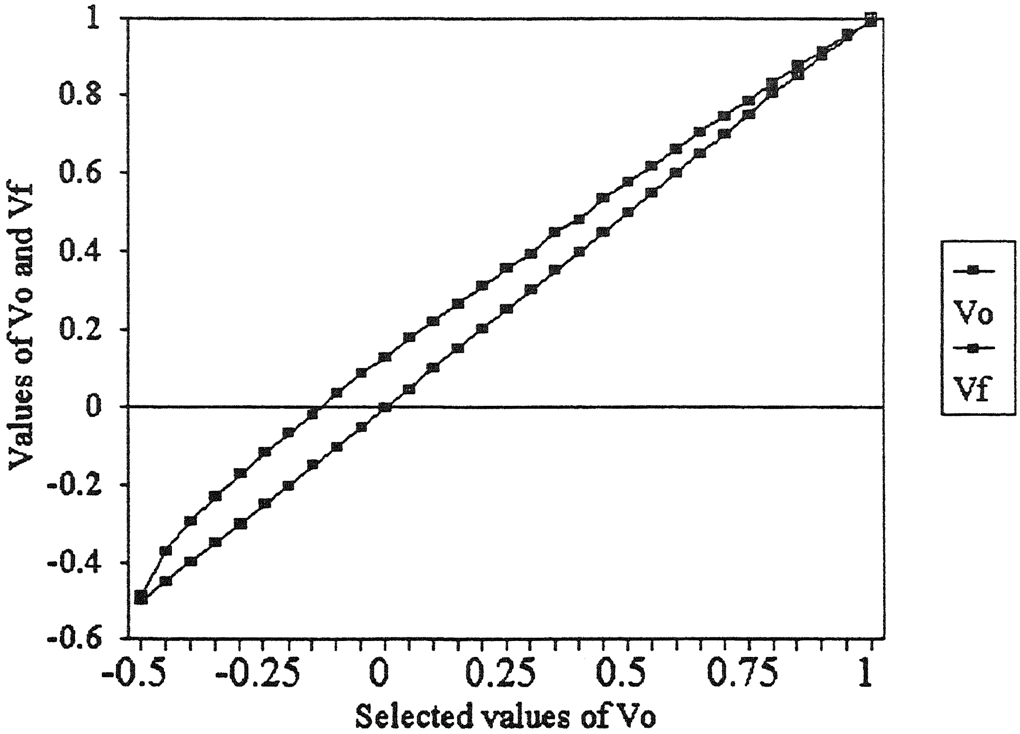


Figure 3: Convergence of V_o and V_f



Finally, the results of hypothesis tests conducted for the bootstrap estimates of V and δ are presented in Table 7. In the classical case, the hypothesis of perfect competition was not rejected in the case of open-loop behavior, but it was rejected for feedback behavior. In the case of the bootstrap estimates, perfect competition is rejected under both open-loop and feedback behavior. The hypothesis of collusive behavior is also rejected in both cases. Only the hypothesis of Cournot-Nash behavior is not rejected. Calculation of the pseudo-standard error also allowed hypothesis testing for δ. For both behavioral assumptions, the hypothesis of δ=0 was rejected. This shows that, even though the absolute value of the parameter is small, it is statistically significant, and the costs of adjustment in banana production are important.

Table 7: Hypothesis Testing for Bootstrapped V and δ

Hypothesis	t-ratio	Remark
$H_0: V_o^B = -0.5,\ H_1: V_o^B > -0.5$	1.70	Reject H_0 at 5%.
$H_0: V_o^B = 0,\ H_1: V_o^B \neq 0$	0.17	Cannot reject H_0.
$H_0: V_o^B = 1,\ H_1: V_o^B < 1$	-2.90	Reject H_0 at any level.
$H_0: \delta_o^B = 0,\ H_1: \delta_o^B > 0$	1.74	Reject H_0 at 5%.
$H_0: V_f^B = -0.5,\ H_1: V_f^B > -0.5$	2.20	Reject H_0 at 5% and 2.5%.
$H_0: V_f^B = 0,\ H_1: V_f^B \neq 0$	0.56	Cannot reject H_0.
$H_0: V_f^B = 1,\ H_1: V_f^B < 1$	-2.70	Reject H_0 at all levels.
$H_0: \delta_f^B = 0,\ H_1: \delta_f^B > 0$	1.76	Reject H_0 at 5%.

4. Summary

This paper has focused on the degree of market power exhibited by firms in exporting bananas to the German market. Using a linear-quadratic dynamic oligopoly model, dynamic conjectural variations parameters were estimated under open-loop and feedback strategies. The results indicate that the German market for banana imports is not perfectly competitive in structure. Using a bootstrapping procedure, the maintained hypothesis of perfect competition is unequivocally rejected, however, the hypothesis that the firms operate in a Cournot-Nash fashion cannot be rejected. In addition, the classical estimate of the dynamic conjectural variations of the feedback model is 0.2, which is greater than the value consistent with Cournot-Nash behavior. The estimates of the adjustment parameter δ are positive and statistically significant in both the open-loop and feedback strategy models. This result supports the hypothesis that there are dynamic production adjustment costs in the banana industry.

In conclusion, the Folk Theorem (Fudenberg and Tirole, 1989) suggests that estimates of conjectural variations, derived in a dynamic setting should turn out to be more collusive than those derived from a static model. This is substantiated by this study. In an earlier paper, Deodhar and Sheldon (1994), using a static model, have derived a conjectural variations parameter for the German banana import market which is lower than the Cournot-Nash value.

In this paper, the dynamic model generates a value which is greater than the Cournot-Nash value, indicating that market appears to be more imperfectly competitive than suggested by results from a static model.

Appendix A:

Converting the open-loop objective function (1) for a representative firm in the matrix form, and writing it in continuous time gives the following expression:

$$\int_0^{\infty} e^{-rt}\left[Ae_i'q_t - \frac{1}{2}q_t'K_iq_t - \frac{1}{2}u_t'S_iu_t\right]dt$$

where the discount factor β is written in terms of discount rate r; $A = (a - \theta_i)$; e_i is the i^{th} unit vector; q_t is the column vector of q_{it}; $K_i = b(ee_i' + e_ie') + \phi_ie_ie_i'$; u_t is the column vector of u_{it}; and $S_i = e_ie_i'\delta_i$, where δ_i is the cost of adjustment parameter of the i^{th} firm. It is assumed that ω_i=0, which implies that adjustment costs are minimized when there is no adjustment. The explicit matrix forms for firm 1, in a triopoly market (n=3) are as below:

$$e_1 = \begin{bmatrix}1\\0\\0\end{bmatrix},\ e = \begin{bmatrix}1\\1\\1\end{bmatrix},\ q_t = \begin{bmatrix}q_{1t}\\q_{2t}\\q_{3t}\end{bmatrix},\ K_1 = \begin{bmatrix}2b+\phi_i & b & b\\ b & 0 & 0\\ b & 0 & 0\end{bmatrix},\ u_t = \begin{bmatrix}u_{1t}\\u_{2t}\\u_{3t}\end{bmatrix},\ and\ S_1 = \begin{bmatrix}\delta_1 & 0 & 0\\0&0&0\\0&0&0\end{bmatrix}.$$

In deriving the first order conditions, attention is restricted to the quadratic part of the problem, since interest lies in imposing restrictions not on the intercept terms, but on the demand slope and the coefficients of the Markov equation[8].

The Lagrangian for the i^{th} firm is written as:

$$L_i = \sum_{t=1}^{T}\beta^{t-1}\left[-\frac{1}{2}q_t'K_iq_t - \frac{1}{2}u_t'S_iu_t + \lambda_{it}'(q_{t-1} + u_t - q_t)\right]$$

where λ_{it} is an (n x 1) column vector. After differentiating the Lagrangian, the following equations emerge:

8. The derivations are borrowed from the original work by Karp and Perloff (1993c). In order to clarify the presentation, intermediate steps have been added.

(A1) $$-K_i q_t - \lambda_{it} + \beta\lambda_{it+1} = 0$$

(A2) $$-V_i' S_i u_t + V_i' \lambda_{it} = 0$$

Here V_i is an (n x 1) column matrix with 1 in the i^{th} row and V_{ij} in the j^{th} row. The term V_{ij} = $\frac{du_{jt}}{du_{it}}$, $\forall\ i \neq j$, and 1, $\forall\ i=j$. For example, the vector V_1 for firm 1 is as follows:

$$V_1 = \begin{bmatrix} 1 \\ V_{12} \\ V_{13} \end{bmatrix}$$

Now, it is assumed that λ_{it} is a linear function of q_t; i.e., $\lambda_{it} = H_{it}q_t$, for some (n x n) square matrix H_{it}. Letting $T \rightarrow \infty$ so that $H_{it} \rightarrow H_i$, equation (A2) becomes:

$$-V_i' S_i u_t + V_i' H_i q_t = 0, \quad i = 1,\ldots,n$$

$$V_i' H_i q_t = V_i' S_i u_t$$

Now simplify the right hand side:

$$V_i' H_i q_t = \delta_i u_{it}$$

(A3) $$\therefore \qquad V_i' H_i q_t = \delta_i e_i' u_{it}$$

Now, equation (A3) conditions are stacked for all firms to get:

(A4) $$Eq_t = Su_t$$

where the i^{th} row of E is $V_i'H_i$, and the i^{th} row of S is $\delta_i e_i'$. u_t is defined as $q_t - q_{t-1}$. Therefore, (A4) can be written as:

$$Eq_t = S(q_t - q_{t-1})$$

$$(E - S)q_t = -Sq_{t-1}$$

$$q_t = (S - E)^{-1}Sq_{t-1}$$

Let:

(A5)

$$(S - E)^{-1}S = G$$

(A6)

$$q_t = Gq_{t-1}$$

Substituting $H_i q_t$ for λ_{it} in equation (A1):

$$-K_i q_t - H_i q_t + \beta H_i q_{t+1} = 0$$

Using (A6) this is rewritten as:

$$(-K_i - H_i + \beta H_i G)q_t = 0$$

$$(-K_i - H_i + \beta H_i G) = 0$$

$$-(H_i - \beta H_i G) = K_i$$

$$H_i(I - \beta G) = -K_i$$

(A7)

$$\therefore \quad H_i = -K_i(I - \beta G)^{-1}$$

From the definition of G in (A5):

$$S = (S - E)G$$

$$S - SG = -EG$$

$$S(I - G)G^{-1} = -E$$

$$\therefore \qquad E = S(I - G^{-1})$$

Pre-multiply both sides of (A4) by e_i' to get:

$$e_i'E = e_i'S(I - G^{-1})$$

$$\therefore \qquad V_i'H_i = \delta_i e_i'(I - G^{-1})$$

Now use equation (A7) to write:

$$-V_i'K_i(I - \beta G)^{-1} = \delta_i e_i'(I - G^{-1})$$

$$-V_i'K_i = \delta_i e_i' \left[(I - G^{-1})(I - \beta G)\right]$$

$$K_i V_i = - \left[(I - G^{-1})(I - \beta G)\right]' e_i \delta_i$$

(A8) $$\therefore \qquad K_i V_i = \left[G^{-1}(I - G)(I - \beta G)\right]' e_i \delta_i$$

This is equation (3) in the text.

Appendix B:

Converting all the variables in into matrix form, the stationary dynamic programming problem can be written as:

$$\left(-\frac{1}{2}q_{t-1}' H_i q_{t-1}\right) = \max \left[-\frac{1}{2}q_t' K_i q_t - \frac{1}{2}u_t' s_i u_t + \beta\left(-\frac{1}{2}q_t' H_i q_t\right)\right]$$

(B1) $$= \max \left[-\frac{1}{2}q_t'(K_i + S_i + \beta H_i)q_t + q_t' S_i q_{t-1} - \frac{1}{2}q_{t-1}' S_i q_{t-1}\right]$$

The first-order condition is:

$$-V_i'(K_i + S_i + \beta H_i)q_t + V_i' S_i q_{t-1} = 0$$

Stacking such conditions for n firms to obtain:

(B2) $$Eq_t = Sq_{t-1}$$

where the i^{th} row of E is $V_i'(K_i + S_i + \beta H_i)$, and the i^{th} row of S is $\delta_i e_i'$. Equation (B2) can be written in the form:

(B3) $$q_t = Gq_{t-1}$$

where $G = E^{-1}S$. Substituting equation (B3) into (B1) gives:

$$\left(-\frac{1}{2}q_{t-1}'H_{iq_{t-1}}\right) = \max\left[-\frac{1}{2}q_{t-1}'G'(K_i + S_i + \beta H_i)Gq_{t-1} + q_{t-1}'G'S_i q_{t-1} + -\frac{1}{2}q_{t-1}'S_i q_{t-1}\right]$$

(B4) $$= \max\left[-\frac{1}{2}q_{t-1}'\left[G'(K_i + S_i + \beta H_i) - G'S_i - S_iG + S_i\right]q_{t-1}\right]$$

(B5) $$\therefore \quad H_i = G'(K_i + S_i + \beta H_i)G - G'S_i - S_iG + S_i$$

Now vectorize equation (B5) by performing the vec operation:

$$Vec\ H_i = Vec\left[G'(K_i + S_i + \beta H_i)G - G'S_i - S_iG + S_i\right]$$

$$= Vec\left[G'(K_i + S_i + \beta H_i)\right] - Vec\left[G'S_i\right] - Vec\left[S_iG\right] + Vec\left[S_i\right]$$

$$= (G' \otimes G')vec\left(K_i + S_i + \beta H_i\right) - (I \otimes G')\ Vec\ (S_i)$$
$$- (G' \otimes I)\ Vec(S_i) + Vec(S_i) - (G' \otimes I)\ Vec(S_i) + Vec\ (S_i)$$

$$\therefore \quad \left[Vec\ H_i - \beta(G' \otimes G')Vec\ H_i\right]$$

$$= \left[(G' \otimes G')Vec(K_i) + \left((G' \otimes G') - (I \otimes G') - (G' \otimes I) + I\right)Vec(S_i)\right]$$

$$\therefore \quad \left[I - \beta(G' \otimes G')\right]Vec\ H_i$$

$$= \left[(G'\otimes G')Vec(K_i) + \left((G'\otimes G')-(I\otimes G')-(G'\otimes I)+I\right)\ \delta_i Vec(e_ie_i')\right]$$

(B6) $$\therefore \quad Vec\ H_i = \left[I - \beta(G' \otimes G')\right]^{-1} \left[(G' \otimes G')Vec(K_i)\right]$$

$$+ \left[I - \beta(G'\otimes G')\right]^{-1} \left[(G'\otimes G') - (I - G') - (G'\otimes I) + I\right] Vec(e_i e_i')\delta_i$$

Equation (B6) can be expressed in short as:

$$Vec\ H_i = \omega_i + x_i\delta_i$$

where ω_i is the first term of the right hand side of (B6), and x_i is the second term except δ_i. Here, $Vec\ H_i$, ω_i and x_i are all (n^2 x 1) column vectors. Therefore, equation (B4) can be converted back in the form of (n x n) vectors by using the inverse-vec(torization) operation. It then takes the form:

(B7) $$H_i = W_i + X_i\ \delta_i$$

where W_i, X_i are the transformed forms of ω_i and x_i having the dimension, (n x n).

Now, once again, consider equations (B2) and (B3). It is known from these equations: $EG = S$. Take the i^{th} row of $EG = S$, i.e.,

(B8) $$V_i'(K_i + S_i + \beta H_i)G = \delta_i e_i'$$

Substitute the value of H_i from equation (B7) into equation (B8):

$$V_i'\left[K_i + S_i + \beta(W_i + X_i\delta_i)\right]G = \delta_i e_i'$$

$$V_i'\left[K_i + \beta W_i + (e_i e_i' + \beta X_i)\delta_i\right]G = \delta_i e_i'$$

$$G'\left[K_i + \beta W_i + (e_i e_i' + \beta X_i)\delta_i\right]' V_i = e_i\delta_i$$

(B9) $$\therefore \quad \left[K_i + \beta W_i + (e_i e_i' + \beta X_i)\delta_i\right]' V_i = G'^{-1}e_i\delta_i$$

This is equation (5) in the text.

Appendix C:

Solving the open-loop model for V and δ

The restriction derived in Appendix A is the following:

$$K_i V_i = \left[G^{-1}(I - G)(I - \beta G)\right]' e_i \delta_i$$

Imposing the symmetry conditions, and expanding the matrices, (assuming n=3):

$$\begin{bmatrix} 2b & b & b \\ b & 0 & 0 \\ b & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ V \\ V \end{bmatrix} = Z_{(3 \times 3)} \begin{bmatrix} \delta \\ 0 \\ 0 \end{bmatrix}$$

where Z is a symmetric matrix, and ϕ_i is assumed to be 0, which implies that marginal cost is constant. The matrices are multiplied to obtain two equations:

$$b = Z_{2,1}\delta$$
$$2b + 2bV = Z_{1,1}\delta$$

$$\therefore \qquad \delta = \frac{b}{Z_{2,1}}, \text{ and } V = \frac{Z_{1,1}}{2Z_{2,1}} - 1$$

Solving the feedback model for V and δ

The restriction derived in Appendix B is the following:

$$\left[K_i + \beta W_i + (e_i e_i' + \beta X_i)\delta_i\right]' V_i = G'^{-1} e_i \delta_i \equiv y_i \delta_i$$

Under the assumption of symmetry, the rank of the matrices in the above equations is two, and we need to look only at the first two equations. Define matrix A^i and B^i so that $Ba^i \equiv K_i + \beta W_i$ and $B^i \equiv e_i e_i' + \beta X_i$. The i^{th} and j^{th} equation is:

$$b\left(A_{ii} + V \sum_{j \neq i} A_{ij}\right) + \left(B_{ii} + V \sum_{j \neq i} B_{ij}\right)\delta = y_{ii}\delta$$

and

$$b\left(A_{ki} + V \sum_{j \neq i} A_{kj}\right) + \left(B_{ki} + V \sum_{j \neq i} B_{kj}\right)\delta = y_{ik}\delta$$

where A_{ij}, B_{ij} and y_{ii} are elements of A^i, B^i and y_i. Solving the second equation gives δ as a linear function of b and a nonlinear function of V. Substituting the value of δ into the first equation gives a quadratic in V that is independent of b. Of the two roots of V, one is closer to the open-loop solution, and the other falls outside the theoretical range. Therefore, the feasible root is picked. Here, V is a function of β and G, and δ is a function of b, β and G.

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